Progress on the Combustion Integrated Rack Component of the Fluids and Combustion Facility

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Abstract. The Fluids and Combustion Facility (FCF) is a facility-class payload planned for the International Space Station. It is designed to accommodate a wide variety of investigations encompassing most of the range of microgravity fluid physics and combustion science. The Combustion Integrated Rack component of the FCF is currently scheduled to be launched in 2003 and will operate independently until additional racks of the FCF are launched. The FCF is intended to complete between five and fifteen combustion experiments per year over its planned ten-year lifetime. Combustion areas that may be studied include laminar flames, reaction kinetics, droplet and spray combustion, flame spread, fire and fire suppressants, condensed phase organic fuel combustion, turbulent combustion, soot and polycyclic aromatic hydrocarbons, and flame-synthesized materials. Three different chamber inserts, one each for investigations of droplet, solid fuel, and gaseous fuel combustion, that can accommodate multiple experiments will be used initially so as to maximize the reuse of hardware. The current flight and flight-definition investigations are briefly described.

COMBUSTION INTEGRATED RACK OVERVIEW

The Fluids and Combustion Facility (FCF) is a facility-class payload planned for the International Space Station that will enable the study of fluid physics and combustion in a microgravity environment (Zurawski, 2000). The combustion experiments that may be conducted in the FCF include, but are not limited to, the study of laminar flames, reaction kinetics, droplet and spray combustion, flame spread, fire and fire suppressants, condensed phase organic fuel combustion, turbulent combustion, soot and polycyclic aromatic hydrocarbons, and flame-synthesized materials. The Combustion Integrated Rack (CIR) is one of three International Standard Payload Racks of the FCF and is being designed primarily to support combustion science experiments. Launch of the CIR is planned for the Utilization Flight-3 in February 2003. It will function independently until the Fluids Integrated Rack (FIR) is launched later that year on Utilization Flight-5. The two racks will share resources such as flight spares and common diagnostics. The launch of the Shared Accommodations Rack (SAR) component of the FCF will occur several years later. It will provide additional capabilities such as housing hardware shared by both the CIR and FIR, experiment stowage volume, facility spares, special purpose hardware, and general purpose interfaces for the operation of small scientific experiments.

The CIR will contain the hardware and software required to support combustion experiments in space. It will contain an optics bench, combustion chamber, fuel oxidizer and management assembly, exhaust vent system, diagnostics, power, environmental control system, command and data management system, and an active rack isolation system. Additional hardware will be inserted in the chamber and on the optics bench that is customized for each investigation. The chamber insert may provide a sample holder or burner, ignition source, flow duct, and small diagnostics such as thermocouples and radiometers. Concepts for the chamber inserts are described in the sections of this paper on droplet, solid fuel, and gaseous fuel combustion.

During the past year, several significant events occurred for the CIR. A Preliminary Design Review was held in April 1999. An independent, non-advocate review panel examined the status of the preliminary design and found that the design was sufficiently mature to continue to the Critical Design Phase. Scientific peers also reviewed the design and concluded that the CIR is eagerly anticipated by the user community and that the preliminary design of the CIR can meet the science requirements needed to accomplish a large variety of microgravity combustion experiments in a timely fashion. Fabrication of an Engineering Model to be used for science and engineering verifications was initiated and should be completed by mid-2000. In addition, several improvements to the design occurred after the Preliminary Design Review. Changes to the diagnostics modules were made in an effort to provide commonality among the diagnostics devices used by the CIR, FIR, and SAR. A common interface is now used on all three racks so that imaging and illumination devices may be shared.

It is expected that the facility will provide most of the capability with a small amount of unique hardware developed for each investigation. When possible, similar investigations will be flown at the same time to increase the use of common hardware and diagnostics. As a way to further reduce the amount of new hardware that needs to be supplied for each investigation, an initial set of three multi-user chamber inserts is being designed. The inserts will contain, to the greatest extent possible, the hardware needed for a class of investigations. Other inserts for singular investigations having requirements not able to be met by the multi-user inserts will be developed as resources permit. Commercial and international investigations will provide their own chamber insert or other resources in exchange for use of a multi-user insert. A total of fourteen flight and flight-definition investigations supported by the microgravity science program and one or more commercial investigations are currently foreseen to use the CIR over the first few years of operation. Several international investigations are at the conceptual stage, and additional microgravity science investigations will be solicited every two years through NASA Research Announcements. Table 1 shows the expected utilization of the CIR from launch through mid-2005. The columns list the launch dates for the three FCF racks and the expected order for the multi-user inserts and the combustion science investigations. Arrows next to the multi-user insert or investigation indicate the direction of transport between the earth and the ISS. *The order in which a particular investigation flies is subject to change based upon results from science reviews, engineering development time, and other factors.* Planning for the time period after that shown here is underway.

TABLE 1. Utilization traffic model for the Fluids and Combustion Facility as of September 1999.

Date/Quarter	STS Flight	FCF Racks	Droplet Combustion[a]	Solid Fuel Combustion[b]	Gaseous Fuel Combustion[c]	Commercial/ International[d]
2/20/03	UF-3	↑ CIR	↑ MDCA ↑ D-1 ↑ D-2			
9/25/03	UF-5	↑ FIR	↑ D-3 ↓ D-1 ↓ D-2			↑ COMM-A
3/18/04	17A		↑ D-4 ↓ D-3			
6/4/04	19A		↓ D-4 ↓ MDCA	↑ MSFA ↑ SF-1 ↑ SF-2		↓ COMM-A
9/23/04	UF6			↓ SF-1	↑ MGFA ↑ GF-1	↑ COMM-B
Jan 05	LF-?			↓ SF-2 ↓ MSFA	↑ GF-2	
Apr 05	LF-?	↑ SAR			↓ GF-1	↓ COMM-B
Jul 05	LF-?			↑ MSFA ↑ SF-3	↓ GF-2 ↓ MGFA	↑ INT(SF-6)

[a]MDCA is the multi-user droplet combustion apparatus, D is a droplet combustion investigation.
[b]MSFA is the multi-user solid fuel apparatus, SF is a solid fuel combustion investigation.
[c]MGFA is the multi-user gaseous fuel apparatus, GF is a gaseous fuel combustion investigation.
[d]COMM is a commercial investigation, INT is an international investigation.

DROPLET COMBUSTION

Four investigations are currently planning to study the combustion of small, spherical droplets of pure and bicomponent alcohol and hydrocarbon fuels. Liquid fuels are a primary source for energy production in the world and the study of their combustion has been ongoing for decades. Nearly all practical uses of combustion involve non-premixed conditions; these are more easily studied using a well defined system such as an isolated droplet. The study of droplet combustion has been and remains a classic combustion problem. One of the investigations, Droplet Combustion Experiment-2, is a reflight investigation; the remaining three are in the early phase of development. For as many investigations as possible, the hardware insert will be based upon the internal apparatus developed for the Droplet Combustion Experiment (Nayagam, 1998). This structure, as shown in Figure 1, contains the droplet deployment mechanisms, hot wire ignitors, fuel supply system, and gas mixing fan. The droplet is generated by issuing fuel from a pair of needles brought together in the center of the test region. The droplet is held between the tips of the needles. The tips are stretched apart slightly after the droplet reaches the proper size (1 to 6 mm dia.) and then are withdrawn rapidly to deploy the droplet. At the moment of droplet deployment, the hot-wire ignitors are activated to ignite the droplet and then they too are withdrawn. The droplet may be deployed into free space or onto a small ceramic fiber. The structure is open on most sides to permit viewing of the droplet and flame. A removable apparatus similar to this will be developed for use in the combustion chamber by several investigations. It is anticipated that at least two droplet investigations will be the first users of the Combustion Integrated Rack after its launch.

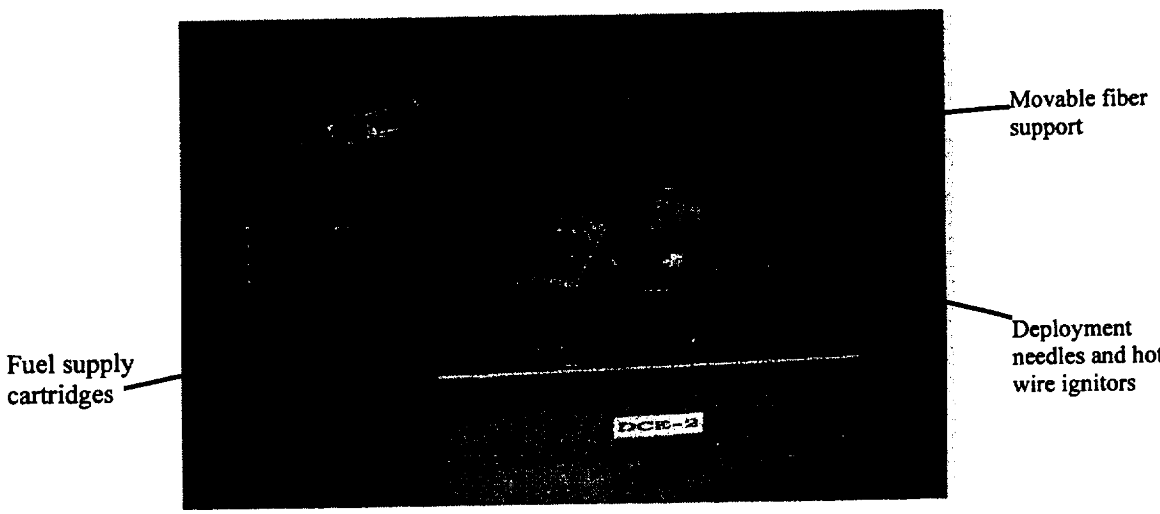


FIGURE 1. Chamber insert apparatus for droplet combustion experiments. The apparatus is placed by an astronaut inside the combustion chamber. At the center of the apparatus are the droplet deployment mechanisms and the hot wire ignitors. The left plate contains the fuel supply cartridges, electrical connections, and crew access handles.

Three investigations will study the combustion of single droplets in a quiescent environment. The Droplet Combustion Experiment-2 (DCE-2) reflight will further explore droplet combustion behaviors, especially those related to extinction phenomena, observed during its first flights on the MSL-1 flights in April and July 1997. The tests use methanol or methanol/water droplets burned in oxygen/nitrogen or oxygen/nitrogen/helium mixtures (Dryer, 1999). The droplet and flame size will be imaged throughout the burn by a backlit view, and color and ultraviolet (OH radical chemiluminescence) cameras, respectively. New measurements for the reflight include a flame view of the CH radical chemiluminescence and a measurement of the flame radiation. The experiment will provide benchmark experimental data sets that can be used for comparison to theoretical predictions of liquid-phase and gas-phase steady and unsteady phenomena, and extinction phenomena. Earlier experiments revealed or verified several phenomena unique to low-gravity, including radiative quenching of the flame and burning at lower oxygen concentrations than in normal gravity.

Another isolated, quiescent droplet experiment, the Bicomponent Droplet Combustion Experiment (BCDCE), has as its focus the internal liquid fluid dynamics and combustion of bicomponent droplets (Aharon, 1997). These tests use droplets composed of a mixture of low volatility and high volatility fuels such as heptane and hexadecane. As the droplet burns, the high volatility component burns off preferentially and the low volatility component is enriched at the droplet surface. At a certain critical time near when the low volatility fraction is near unity, the droplet surface heats rapidly and a contraction in flame size is observed. This indicates a loss of the high volatility component at the droplet surface. Measurements of the droplet and flame size, similar to those in the Droplet Combustion Experiment, will be made. An additional measurement of the droplet internal flow field is also being sought. This experiment will be the first to study how the internal flow dynamics and combustion of a burning droplet are driven by liquid species transport and capillary forces.

Sooting behaviors of droplets are the focus of the Sooting Effects in Droplet Combustion (SEDC) investigation (Manzello, 1999). The goal of this experiment is to perform detailed quantitative measurements of the soot concentration and temperature distributions and soot morphology in single, isolated burning droplets. These experiments will measure the influence of soot on droplet burning rate, flame structure, and flame extinction. An isolated droplet of n-heptane or ethanol in oxygen/nitrogen, oxygen/helium or oxygen/nitrogen/helium mixtures will be burned. Based on observations in the ground-based reduced-gravity facilities, the formation and presence of soot can modify the burning droplet behavior. An understanding of the formation, transport, and oxidization of soot is important for control of desired or undesired sooting behaviors.

In contrast to the first three droplet investigations in a quiescent environment, the fourth investigation, Dynamic Droplet Combustion Experiment (DDCE), plans to study droplet combustion in the presence of low-speed convective flows such as may be found in the ventilation systems of space vehicles (Nayagam, 1999). This investigation will focus on understanding the influences of convection on the radiative extinction that occurs when excessive radiative heat loss from the flame zone leads to flame extinction. An isolated fuel droplet will be deployed onto a small ceramic fiber. Translation of the fiber through the test section or the use of a flow duct with a low-speed fan will provide the slow convective environment. At various speeds and oxygen concentrations, the elliptical flame may completely envelope the droplet or may break open in the droplet's wake. Measurements of the droplet diameter, flame shape, and radiant energy output of the flame will be made. The data will be compared to theoretical models that predict the radiative extinction flammability boundary. The investigation will improved the understanding of enhanced fire safety margins in spaceflight as well as help to interpret the measurements made of freely deployed droplets having a small, residual velocity.

SOLID FUEL COMBUSTION

Six investigations are currently planned for the study of the combustion of small solid fuel samples. The study of solid fuel combustion is important for the development of better material flammability tests and predictions, and models of flame ignition, spread, and extinction in solid materials. Improved fire prevention and extinguishment on the earth and in spacecraft are potential benefits of this research. Unwanted fires result in a significant number of deaths and lost property each year on the earth, and the possibility of an accidental fire in a spacecraft remains a concern. The first two investigations discussed below passed their first science reviews and are in requirement definition and engineering concept formulation phase. The remainder are beginning their initial phases of science concept formulation. Preliminary requirements from these investigations are guiding the development of a chamber insert capable of being used by as many investigations as possible within the resources available for its development. Most of the investigations require a sample holder, a flow duct to provide a low speed convective flow environment, an ignition system, and a clear volume for imaging of the flame and solid fuel surface. It is anticipated that at least two solid fuel investigations will be performed in the CIR using this new apparatus after the completion of several droplet combustion experiments in their apparatus.

One investigation, Solid Inflammability Boundary at Low Speed (SIBAL), studies the effect of low-speed, concurrent flow on the spreading and extinction processes of flames over a thin, solid fuel (T'ien, 1999). The investigation seeks to verify the theoretically predicted extinction boundary. In particular, the low-speed quenching limits and the existence of the critical oxygen flammability limit are sought. Theoretical models and previous microgravity experiments show that flame spread and extinction phenomena in low-speed flows are fundamentally different from that found in higher-speed flows, such as are encountered on earth. In this investigation, a thin solid fuel ribbon is placed into a low-speed flow duct. After the gas flow is established, the sample is ignited using a hot wire. As the fuel is consumed by the flame, the ribbon moves to supply fresh fuel in order to maintain the flame at a fixed position in the flow duct. The flammability boundary is mapped out by observing the flame extinction upon varying the oxygen concentration or the gas flow rate. Measurements of the flame shape, structure, temperature, and heat release, and the fuel burnout rate will be made. The investigation will validate a model of flame spread and extinction that predicts the existence of a critical low oxygen limit in concurrent flow. The existence of this fundamental limit is of scientific interest and has implications for spacecraft fire safety.

Another investigation studying solid fuels in low-speed flows is the Transition from Ignition to Flame Growth under External Radiation in 3-D (TIGER-3D) investigation (Kashiwagi, 1999). The objective of this investigation is to study the processes that control the ignition and subsequent transition to flame spread for solid fuels. The effects of external radiant flux distribution and flow velocity, sample configuration, and oxygen concentration will be studied. Samples of paper and polymethylmethacrylate (PMMA) will be placed into a flow duct. Once the gas flow is established, the sample will be radiantly ignited in either a 2-D (line) or 3-D (dot) configuration. Measurements of ignition shape and time, flame shape, structure, and color, and gas and surface temperatures will be made. The results will be used to validate an extensive computer model that predicts initiation of fire and its growth in microgravity with material characteristics as inputs to the model. The model could be further developed to apply to the normal gravity selection of materials for terrestrial applications.

The Forced Ignition and Spread Test (FIST) investigation seeks to develop a standard testing method to assess the flammability of solid materials for spacecraft applications (Cordova, 1999). A new flammability apparatus, shown in Fig. 2, will be tested in anticipation that it will better reflect the potential ambient conditions of space-based environments. The goal is to use the apparatus to obtain improved flammability diagrams for common materials as they are used in space facilities. The sample fuels are PMMA and composites such as those used on aircraft. The apparatus under test uses a radiant panel to provide an incident flux to a large portion of the fuel surface. A low speed flow is passed over the fuel to simulate the flow environment aboard spacecraft. Ignition is provided by a hot wire located in the region where vapors from the fuel pass. The time to ignition, flame spread rate, and surface temperature are measured as the amount of radiant flux and exposure time are varied. Theoretical modeling and normal gravity experiments will support the tests. The improved testing method could lead to a better determination of the fire hazard characteristics of materials for spacecraft. The goal is to develop and validate a simple model based on the material properties and the critical heat flux that will allow materials to be ranked in terms of their propensity to ignite and spread rapidly.

An investigation using both low speed flow or no flow is Radiative Enhancement Effects of Flame Spread (REEFS) (Honda, 1998). The effects of inert components such as carbon dioxide in the atmosphere and low speed flows on flame spread rates across solid fuels will be studied. Since fires in enclosures with insufficient oxygen for complete combustion often produce carbon monoxide and unburned or partially burned gaseous fuel molecules, some tests will be done in the presence of small amounts of gaseous fuel to see if the flame will burn stronger or faster. Several fuels are being considered for study with thick polystyrene foam samples being the leading candidate. Images of the flame will provide flame spread rates and flame shape. Temperature measurements and radiometers provide information on the heat flux from the gas phase to the fuel surface. The study of fires with carbon dioxide as a diluent is particularly relevant to fire safety on the International Space Station, as its fire extinguishers will use carbon dioxide, or in a Martian environment.

Finally, an investigation named Analysis of Thermodiffusive and Hydrodynamic Instabilities in Near-extinction Atmospheres (ATHINA) will study the details of the breakup of a steadily propagating, uniform flame front into a corrugated flame or small, individual flamelets (Wichman, 1999). In normal gravity, buoyancy overwhelms these instabilities and produces planar flames. Unstable flame fronts have been observed in microgravity for diffusion flames of candles and thin solid fuels, often in cases where there is significant heat loss to a nearby cold, solid surface. The spaceflight investigation will use wide samples in a low-speed flow of air. Measurements of the flame shape and structure as it forms the flamelets will be made for comparison to a theoretical model.

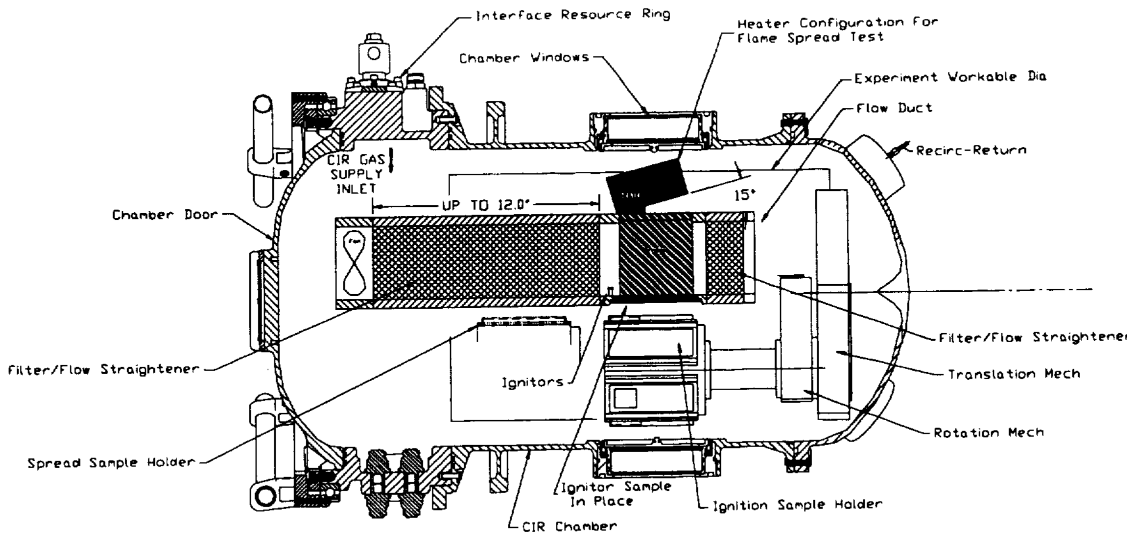
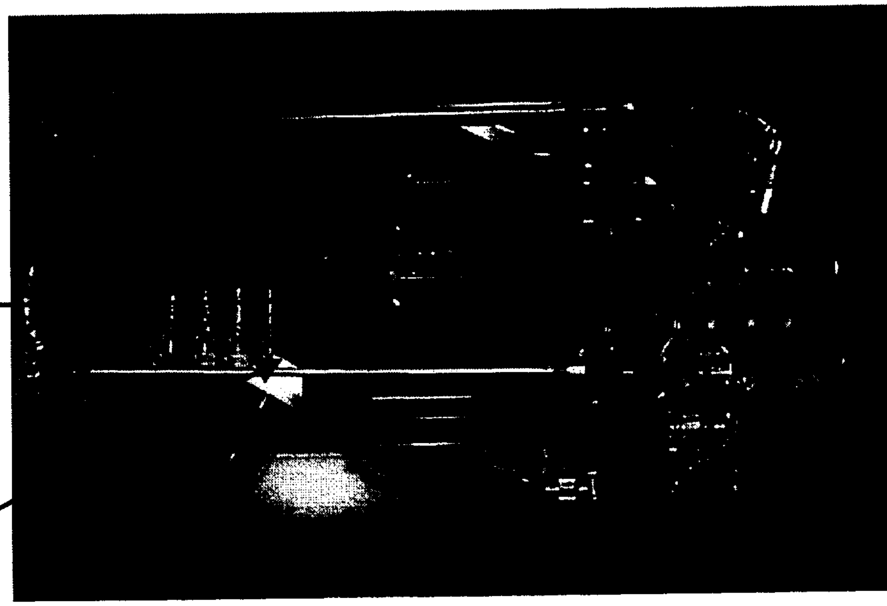


FIGURE 2. Schematic of chamber insert apparatus for FIST solid fuel experiment. The apparatus is placed by an astronaut inside the combustion chamber. At the center of the apparatus are the flow duct, radiant heater, sample holder carousel and the hot wire ignitors. Flow travels through the duct from right to left.

GASEOUS FUEL COMBUSTION

Six investigations are currently planned for the study of various types of gaseous fuel combustion. Both premixed and nonpremixed gaseous combustion using nozzles of various sizes, flame vessels and tubes, and porous spherical burners will be studied. Gaseous combustion occurs in many practical systems as well as in unwanted fires. The use of gaseous fuels simplifies the study of the main processes in combustion, chemical reaction and heat and mass transfer. All of these investigations discussed below are in the science concept formulation phase of their development and will undergo several science reviews. For as many experiments as possible, the hardware insert will be based upon the chamber insert (see Fig. 3) developed for the Laminar Soot Processes experiment flown in the shuttle-based Combustion Module (Urban, 1998). This structure contains a small fuel nozzle and hot wire ignitor, and a far-field thermocouple rake, flame radiometer, and thermophoretic soot samplers. During the experiment, fuel issues from the nozzle into a quiescent chamber filled with oxidizer. A hot wire ignitor positioned near the nozzle tip ignites the flame. When the data collection is complete, the fuel flow is ended and the flame extinguishes. The reflight of a commercial investigation studying the efficacy of water mist as a fire suppressant is also planned.

Two investigations using a porous sphere burner will study various aspects of nonpremixed diffusion flames. One is the Structure and Response of Spherical Diffusion Flames (s-Flame) investigation (Law, 1999). The investigation will study the structure and dynamics of diffusion flames in simple, well defined flow fields. The emphasis is on various issues related to unsteadiness, kinetics and extinction, flame front instabilities, vortical flow motion, and partial premixing. A spherically-symmetric diffusion flame is generated by discharging fuel from a porous spherical burner into a quiescent, oxidizing ambient atmosphere. The burner may be rotated to produce a vortical flow field around the burner. Oxidizer and inert will also be discharged to create partially premixed or diluted flames. Parameters to be controlled are the fuel flow rate, oxidizer and inert concentration in the fuel stream, and the burner rotation rate. Fuels are hydrogen, methane, ethylene, propane, butane, methanol and pentane. Temperature measurements of the burner surface, chamber wall, and flame, and flame images using color, infrared, and ultraviolet sensors will be made. The practical application of this investigation will lead to approaches for achieving energy conversion efficiencies and reduction of pollution in such flames.



Soot samplers

Hot wire ignitor

Fuel nozzle

Flame radiometer

FIGURE 3. Chamber insert apparatus for Laminar Soot Processes experiment. The apparatus is placed by an astronaut inside the combustion chamber. At the center of the apparatus are the fuel nozzle, hot wire ignitor, and flame radiation detector. The left side contains the thermophoretic soot samplers. The right side contains the electrical and gas connections and crew access handles.

The other investigation using the porous sphere burner is Flame Design (Sunderland, 1999). The investigation will study the relative importance of structure and flow inversion on soot inception and flame extinction and determine which is the dominant mechanism for soot suppression at high stoichiometric mixture fraction. The microgravity flames are uniquely capable of allowing independent variation of the convective direction and flame structure while maintaining constant flame temperature. The investigation studies the effects of fuel flowing into quiescent oxidizer or the reverse, oxidizer flowing into quiescent fuel (flow inversion). It will also study the effects of removing nitrogen from air, leaving behind the oxygen, and adding the nitrogen to the fuel (structure inversion). Four flames will be studied: i) fuel issuing into air, ii) diluted fuel issuing into oxygen, iii) air issuing into ethylene, and iv) oxygen issuing into diluted fuel. Measurements of the soot inception limits, fundamental flammability limits, and minimum extinction temperatures will be made. Preliminary work in the reduced-gravity drop tower shows dramatic reduction in soot for cases ii and iv. The study of these flames will lead to designs that best optimize efficiency and minimize pollutants, specifically soot and NOx.

A premixed flame investigation is Lean Premixed Turbulent Flames (Cheng, 1999). The objective of this experiment is to characterize flame structures and flowfields of lean premixed laminar and turbulent flames. Turbulent combustion, which involves a complex coupling of chemical and fluid mechanics, is a crucial issue for combustion. The microgravity environment will provide data needed by the experiment to understand the coupling between local effects and field effects on flame structures. The experiment uses a nozzle to produce an inverted-conical flame stabilized by a small bluff body. Turbulence is generated by the use of a grid or perforated plates place upstream of the flame stabilizer. Methane and air are premixed in various equivalence ratios. Scalar measurements from flame images are of the mean flame angles and the evolution of turbulent flame wrinkle scales. Velocity measurements using laser velocimetry are of the combustion-generated flow deflection, flow acceleration, and turbulence. The practical applications from this investigation will be to guide the development of turbulent combustion models to include the effects of gravity. This would allow enhancement of the burning rates and volumetric power density in many heating and power generating systems.

Another investigation studying turbulence, the Pulsed-Fully Flames (PUFF) experiment, uses nonpremixed combustion to increase the fundamental understanding of the fuel/air mixing and combustion behavior of fully-modulated (pulsed), turbulent diffusion flames (Hermanson, 1999). Specifically, this investigation will determine the mechanisms responsible for flame length decrease of these flames as compared to unmodulated flames, how the mixing and combustion characteristics are impacted by buoyancy, the nature of turbulent fuel puffs at high Reynolds number in the fully momentum-dominated regime, and the conditions under which these flames behave like steady diffusion flames. Microgravity allows the flame flickering to be produced in a controlled manner. The experiment will have a coflow diffusion flame with fuel supplied to a core and pilot flame nozzle. The fuel is methane or propane diluted with nitrogen. The fuel to the core nozzle is capable of being turned on and off at rates from 0.5 to 15 Hz. A steady co-flow of oxidizer is supplied to the combustor chimney. Measurements will be made of the flame size and structure, exhaust gas composition, temperature and pressure, and flow field imaging to determine air entrainment. This investigation has applications to pulsed combustion devices such as those used in furnaces, heaters, dryers, and incinerators. Pulsing accelerates the fuel/air mixing and combustion rate, thereby increasing the thermal efficiency and heat transfer, while reducing the formation of pollutants such as soot, carbon monoxide, and NOx.

One of the premixed flame investigations, Cool Flames, will study diffusively-controlled, low-temperature oxidation reactions and cool flames under static conditions (Pearlman, 1999). The experiment will be conducted in a small, heated, quartz flask filled with a mixture of fuel and oxygen. The gases will auto-ignite and react at low temperatures over the course of seconds to days, depending on the initial temperature and pressure. Flame images, temperature and pressure measurements, and chemical analysis of the combustion gases will be made. An improved understanding of low temperature oxidation reactions and cool flames will improve the design and selection of operational parameters for internal combustion engines, and could improve the understanding of engine knock, engine run-on, and autoignition. A unique experiment insert will be designed for this experiment.

Another premixed flame investigation, Water Mist, uses a premixed flame to test the efficacy of fine water mists for fire suppression (Abbud-Madrid, 1999). The objective is to study the fundamental interaction of a flame with a water mist in a simple, well-defined experimental setup such as can be produced in microgravity. A premixed propane – air mixture is loaded into a flame tube. Part of the tube will be filled with a fine mist of water droplets. The flame is ignited in the dry section and propagates down the tube to encounter the mist. The flame speed will be measured with photodiodes and cameras. Measurements of water mist density and droplet size will also be made. The use of water mist technology is being considered as a replacement for halogen-based chemical agents. This investigation is sponsored by the NASA Center for Commercial Applications of Combustion in Space, who is also building the experiment insert.

CONCLUDING REMARKS

The Combustion Integrated Rack of the Fluids and Combustion Facility is proceeding through its design phase so as to support a planned launch in 2003. The preliminary design will accommodate a wide variety of investigations encompassing most of the range of microgravity combustion science and will complete between five and fifteen combustion experiments per year over its planned ten-year lifetime. Three different chamber inserts that can accommodate multiple experiments, one each for investigations of droplet, solid fuel, and gaseous fuel combustion, will be used initially so as to maximize the reuse of hardware. A total of fourteen flight and flight-definition investigations supported by the microgravity science program and one or more commercial and international investigations are currently foreseen to use the CIR over the first few years of operation.

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REFERENCES

Abbud-Madrid, A., Riedel, E. P., and McKinnon, J. T., "A Study of Flame Propagation on Water-Mist Laden Gas Mixtures in Microgravity," in *Proceedings of the Fifth International Microgravity Combustion Workshop*, edited by K. Sacksteder, NASA/CP—1999-208917, 1999, pp. 65-68.

Aharon, I., and Shaw, B. D., "On the Roles of Thermal Diffusion and Distinct Binary Diffusion Coefficients in Modeling Droplet Flame Locations in Microgravity," *Microgravity Science and Technology* **X/2**, 75-85 (1997).

Cheng, R. K., Bedat, B., and Kostiuk, L. W., "Effects of Buoyancy on Lean Premixed V-Flames Part I: Laminar and Turbulent Flame Structures," *Combustion and Flame* **116**, 360-375 (1999).

Cordova, J. L., Walther, D. C., Fernandez-Pello, A. C., Steinhaus, T., Torero, J. L., Quintiere, J. G., and Ross, H. D., "Flow Effects on the Flammability Diagrams of Solid Fuels: Microgravity Influence on Ignition Delay," in *Proceedings of the Fifth International Microgravity Combustion Workshop*, edited by K. Sacksteder, NASA/CP—1999-208917, 1999, pp. 35-38.

Dryer, F. L., "Some Recent Observations on the Burning of Isolated n-Heptane and Alcohol Droplets," in *Proceedings of the Fifth International Microgravity Combustion Workshop*, edited by K. Sacksteder, NASA/CP—1999-208917, 1999, pp. 19-22.

Hermanson, J. C., Johari, H., Useowicz, J. E., Stocker, D. P., Nagashima, T., and Obata, S., "An Experimental Investigation of Fully-Modulated, Turbulent Diffusion Flames in Reduced Gravity," in *Proceedings of the Fifth International Microgravity Combustion Workshop*, edited by K. Sacksteder, NASA/CP—1999-208917, 1999, pp. 455-458.

Honda, L., and Ronney, P. D., "Effect of Ambient Atmosphere on Flame Spread at Microgravity," *Combustion Science and Technology* **133**, 267-291 (1998).

Kashiwagi, T., Mell, W., Baum, H., and Olson, S., "Ignition, Transition, Flame Spread in Multidimensional Configurations in Microgravity," in *Proceedings of the Fifth International Microgravity Combustion Workshop*, edited by K. Sacksteder, NASA/CP—1999-208917, 1999, pp. 333-336.

Law, C. K., Tse, S. D., He, L., Zhu, D. L., and Sung, C. J., "Structure and Transient Response of Spherical Flames," in *Proceedings of the Fifth International Microgravity Combustion Workshop*, edited by K. Sacksteder, NASA/CP—1999-208917, 1999, pp. 73-76.

Manzello, S. L., Hua, M., Choi, M. Y., and Dryer, F. L., "Experiments and Model Development for the Investigation of Sooting and Radiation Effects in Microgravity Droplet Combustion," in *Proceedings of the Fifth International Microgravity Combustion Workshop*, edited by K. Sacksteder, NASA/CP—1999-208917, 1999, pp. 241-244.

Nayagam, V., Haggard, J. B., Jr., and Williams, F. A., "Dynamics of Droplet Extinction in Slow Convective Flows," in *Proceedings of the Fifth International Microgravity Combustion Workshop*, edited by K. Sacksteder, NASA/CP—1999-208917, 1999, pp. 461-463.

Nayagam, V., Haggard, J. B., Jr., Colantonio, R. O., Marchese, A. J., Dryer, F. L., Zhang, B. L., and Williams, F. L., "Microgravity n-Heptane Droplet Combustion in Oxygen-Helium Mixtures at Atmospheric Pressure," *AIAA Journal* **36**, 1369-1378 (1998).

Pearlman, H., "Low-Temperature Oxidation Reactions and Cool Flames at Earth and Reduced Gravity," in *Proceedings of the Fifth International Microgravity Combustion Workshop*, edited by K. Sacksteder, NASA/CP—1999-208917, 1999, pp. 175-178.

Sunderland, P. B., Axelbaum, R. L., and Urban. D. L., "Effects of Structure and Hydrodynamics on the Sooting Behavior of Spherical Microgravity Diffusion Flames," in *Proceedings of the Fifth International Microgravity Combustion Workshop*, edited by K. Sacksteder, NASA/CP—1999-208917, 1999, p. 475-477.

T'ien, J. S., Ferkul, P., Sacksteder, K., Shih, H.-Y., Bedir, H., Greenberg, P.S., Pettegrew, R. D., Piltch, N., and Frate, D., "Solid Inflammability Boundary at Low Speed (SIBAL)," in *Proceedings of the Fifth International Microgravity Combustion Workshop*, edited by K. Sacksteder, NASA/CP—1999-208917, 1999, p. 15-18.

Urban, D. L., Yuan, Z.-G., Sunderland, P. B., Linteris, G. T., Voss, J. E., Lin, K.-C., Dai, Z., Sun, K., and Faeth, G. M., "Structure and Soot Properties of Nonbuoyant Ethylene/Air Laminar Jet Diffusion Flames," *AIAA Journal* **36**, 1346-1360 (1998).

Wichman, I. S., and Olson, S. L., "Investigation of Diffusion Tip Thermodiffusive and Hydrodynamic Instability under Microgravity Conditions," in *Proceedings of the Fifth International Microgravity Combustion Workshop*, edited by K. Sacksteder, NASA/CP—1999-208917, 1999, p. 163-166.

Zurawski, R.L., "The FCF Combustion Integrated Rack," AIAA 2000-0425, 38th Aerospace Sciences Meeting & Exhibit, Reno, NV, 2000.

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